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ABSTRACT

This paper proposed to apply the perspective of constructivism to the classroom setting. Secondary science teachers and university personnel jointly developed and experimented with a variety of constructivist teaching strategies. Data were collected in the form of teacher anecdotes, audio and videotapes of lessons and student interviews, teacher developed instructional materials and student products, and were subsequently discussed and conceptualized by the joint investigators. This rather unique collaborative research model effectively blurred the more typically distinct boundary between theory and practice seen in many other research methodologies. The blurrier the distinction between theory and practice, stereotypically assigned to researchers and practitioners respectively, the greater is the relevance one has to the other. Collaborative research involving school teachers and university personnel has great potential for mutual benefit as reported from the work of this project. (MVL)

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CONSTRUCTIVISM AND PROFESSIONAL DEVELOPMENT: A STEREOSCOPIC VIEW

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INTRODUCTION

Constructivism is grounded in a particular theory of learning which postulates that knowledge is personally constructed out of one's own unique set of experiences. There has been a considerable amount of literature produced in recent years which detail this view of learning (Erickson, 1983, Driver and Oldham, 1986, Osborne and Freyberg, 1985, Barnes, 1976, Bereiter, 1985) and while is not the primary purpose of this paper to restate the theoretical discourse, it is hoped that the notion of constructivist learning can be shown to be germane to a variety of educational contexts and, in particular, how the theory is manifest in practical ways in the instruction of both science students and preservice student teachers.

This framework has been developed largely out of practical, personal experience, the author having had the rather unique opportunity in recent years of adopting each of the roles of: classroom teacher, student teacher school supervisor, prepracticum secondary science methods instructor at the university level, and practicum faculty supervisor. Constructivism has been the basis for both the pedagogical perspective and the agenda throughout; that is to say, 1) the strategies which were implement in teaching hopefully reflected a commitment to student-centeredness, a consideration of and respect for students' prior beliefs or alternate conceptions, and have been consistent with the view of learning as "conceptual change" (Driver, 1987); and 2) it is intended that this propositional knowledge becomes integral to the personal values and practice of student teachers.

CONSTRUCTIVISM AND SCIENCE TEACHING

Building on the epistemological foundation of constructivism Erickson (1984) proposed to apply the perspective to the classroom setting (Erickson, 1988). Utilizing an "action research" model described by Schon, (1983) secondary science teachers and university personnel jointly developed and experimented with a variety of "constructivist" teaching strategies. The author was one of the three project teachers. Data was collected in the form of teacher anecdotes, audio and videotapes of lessons and student interviews, teacher-developed instructional materials and student products, and were subsequently discussed and conceptualized by the joint investigators. This rather unique collaborative research model effectively blurred the more typically distinct boundary between theory and practice seen in many other research methodologies. As Erickson noted, the model was clearly a

departure from what was initially envisaged as a

> ". . . model (which) clearly represents the classic distinction between theory being generated by researchers and the technical implementation of that theory into practice by the classroom teacher." (Erickson, 1988, p. 2)

Over the duration of the project there were frequent opportunities for the project personnel to exchange anecdotes of classroom experiences, negotiate perceptions and personal meaning thereby developing compatible theoretical interpretations, common language (Erickson, 1988), and a clarification of objectives. The "[SI]^2 " Group as it became to be known (a euphemism for "Students' Intuitions and Science Instruction") were primarily concerned with developing and testing teaching manoeuvres which are consistent with the following tenets of constructivism:

1. The learner actively constructs knowledge in an attempt to make sense and order of the world and seek patterns which enables the prediction of phenomenological outcomes.
2. The cognitive structures (i.e. the models, metaphors, symbols and connections between concepts) which are constructed by the learner are as unique and personal as the experiences from which they are assembled.
3. These prior beliefs are often inconsistent with the socially constructed knowledge of contemporary science.
4. New knowledge must be accommodated and reconciled with existing ideas, the nature of which may influence the interpretations made or personal meaning derived from new experiences.
5. Alternate conceptions are tenaciously held by the learner in a manner reminiscent of the paradigms of "normal science" described by Kuhn (1962) in the context of the scientific community.

These tenets have profound implications for practice, suggesting particular characteristics and sequence of instruction that Driver and Oldham (1986) have set out in a pedagogical framework shown in Figure 1.

The *orientation* phase is similar to what Hawkins terms a "starting point"-- an experience which introduces a topic and intrigues the learner, having the qualities which would allow for "branching" into a number of areas and the posing of "fresh questions".

When approaching a new theme, the learner brings into play a selection of what is perceived to be relevant intuitions, beliefs and attitudes borne out of past experiences. These can be viewed as the tools used to shape meaning out of new experiences, or perhaps as tentative "hooks" upon which new ideas can be hung. Using a constructivist metaphor, the conceptions derived from experiences of both past and present mutually modify one another and are assembled in the

construction of current thinking.

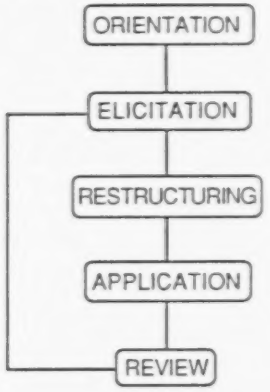

FIGURE 1: "Constructivist Teaching Sequence"
(From Driver and Oldham, 1986)

The identification of the preconceptions is, of course, central to the constructivist perspective in view of our belief that existing ideas influence the interpretation of new ones. "Concept mapping" is a strategy described by Novak (1984) and employed by Seiben (1987) for the *elicitation* of students' conceptions prior to formal instruction. The student lists a number of single-worded terms or "concepts" surrounding a particular theme, for example,"animals", "trees" and "water" as they pertain to the theme of "nature". These concepts are distributed on a broad sheet of paper and the student makes connections among those considered to be related in some way. Connection lines are labelled in a manner which describes that relationship; for instance, "is needed by" or "is an example of", etc. The teacher can make inferences about the students' preconceptions on the basis of the concepts selected and the nature of the connections which are either made or omitted. Alternatively, the concept map may serve as a focus for a teacher/student dialogue where the opportunity may be taken to seek clarification about particular student ideas.

In other strategies, Kuhn (1987) elicited students' ideas through the use of cartooning, student metaphors, and journal entries (to be discussed later). Additionally, the author has encouraged students to make predictions for the outcome of an observable phenomenon as part of a

"Predict-Observe-Explain" ("P. O. E.) sequence, described later) which forces the student to come to terms with and to articulate their beliefs by making application to a real setting. In a starkly forthright technique the author irreverently terms "pre-instructional dipsticking", students are simply asked to describe what they believe to be true about selected topics; for example, "what causes gravity?" or "what happens to food when you eat it?". They are also asked to give a justification for their beliefs if they are able to. Although this is frequently difficult for the students, it gives them pause to look inwards, raises their interest and curiosity, and occasionally provides fascinating insights. Here are some interesting student responses to the gravity question:

> -"Gravity is caused by the movement of earth through space. It is kind of like when you are running you can put a piece of paper on your chest and it sticks there."
> -"Gravity is caused by a magnet in the center of the earth. That is why metals are heavier than non-metals."
> -"Gravity is caused by the magnetism in the earth's core. That is what my grade 5 teacher told me and if it isn't right then that's her fault!"

Unfortunately, students are not always so obliging as to provide us with translations for their particular beliefs in terms of their past experiences or the conceptual connections they are making. The phrase that Schon (1989) uses to describe the giving of what I called "translations" to student utterances is "giving the student reason". He provides some delightful examples, one involving two boys separated by an opaque screen and with blocks of various colours and shapes placed before them. One boy gives verbal instructions to the other on how to assemble a particular pattern of blocks. Before long the second boy becomes lost. However, while viewing a videotape of the incident afterwards, it became clear to the investigators that the reason the second boy goes astray is not his inability to follow instructions, but rather an instruction that was impossible to follow given the blocks before him. A faulty instruction was the "reason" that could be given the second boy to account for his difficulty in reproducing the pattern.

Let me illustrate further with an example of my own. My daughter, then three and a half years old, asked me to bring her a glass of orange juice and I dutifully obliged. She looked up at me and asked "How long did you pour it?" I considered this a worthwhile opportunity to "give reason" for this bewildering question, so I asked her what she meant. She regarded me like an idiot and repeated the question with more emphasis so that I could better understand. I probed with a number of questions that

only frustrated her more. What was she asking me? How full was the pitcher? How long did it take me to pour it? Was this a question of time? Volume? Viscosity? I got nowhere with it because she simply lacked the vocabulary to make it clear to me while I was unable to pose the key question. A year later I was preparing for a lesson involving "giving reason" for my university Methods class. I eyed my daughter who was blissfully sipping orange juice. I asked her if she remembered the incident and, remarkably, she did. What did she mean? Now we had the words that conveyed the right meaning, and I finally understood that she was asking me how long the stream was, in other words, "how high did I hold the pitcher when I poured?" The reason she was interested was that a good splash creates a frothy "head" and that is how she likes to drink it!

Apart from simple elicitation strategies, the teacher requires patience, perseverance, and above all a disposition to want to make sense of student utterances if an accurate sense of their thinking is to be made. Language was at the heart of the problem involving my daughter's comment, but this is not confined to the domain of pre-schoolers. What does the fourteen year old mean when he says that "salt acts as a reverse catalyst on ice" or that one's ears pop when ascending because "the air is colder up there?" Schon's notion of "reflection in action" describes the kind of experimentation undertaken to unravel the meaning embedded in student dialogue by speculating, hypothesizing, testing, exploring, rechecking, and revising. There is a great deal of complexity in the way that anyone constructs meaning. In fact, certain beliefs may be rather "slippery" and context-specific, further reinforcing the need expressed here for the clarification, elaboration and justification by students in the expression of their thinking.

In consideration of the personal nature of preconceptions, one characteristic of purposeful and effective elicitation strategies is critical: the student must sense a safe, low-risk environment free from evaluation by either teacher or peers. Ideas must be accepted without criticism, but with the understanding that hypotheses should be testable and subject to verification or falsification. A safe environment is one where students are free to wonder out loud, where the asking of questions is encouraged, where there is the freedom to offer opinions and ideas and to voice agreements or disagreements with those of others, but where there is the expectation that justification be given for contrary beliefs.

An "interpretive discussion" (Mitchell, 1986 and Gurney, 1988) is a strategy in which student ideas are offered and debated in an open classroom forum. In it, the role of the teacher is that of a neutral

mediator among: 1) the ideas offered by individual students; 2) students ideas and those of contemporary science; and 3) students' ideas and observable phenomena. Praise can and should be offered for ideas which are creative or clearly expressed but teacher judgement on the "correctness" of ideas should be minimized. There are at least two reasons for this, the most obvious of which relates to the psychological effects of judgement on one's willingness to contribute personal thinking. The other is concerned with the nature of "knowing" that is consistent with a constructivist perspective; that is to say, knowledge which is transmitted from an authority in authority has more limited potential for assimilation into one's personal cognitive framework than knowledge which is derived from experience and the personal interpretation of that experience. The body of scientific knowledge has been accumulated and modified through observation, hypothesis testing and the negotiation of ideas through social interaction, not by consulting an "owner's manual" of the universe. It is my assertion that transmissive instruction in a setting where the teacher is the gatekeeper of scientific truth fosters a particular attitude--a preconception, if you will--about the nature of science that one carries into adulthood. Consider the implications of this in terms of a kind of "pedagogical hegemony"; a fraction of these students who are products of transmissive instruction become teachers themselves!

Restructuring refers to the set of tactics which, in Driver's words, "promotes conceptual change", where "conceptual change"--the modification of prior beliefs to conform more closely with socially constructed knowledge--is the constructivist's view of learning. Accretionary knowledge must be accommodated within existing structures if the learner is to take ownership, otherwise it is set in isolation, perhaps remembered but not believed. Restructuring involves the reconsideration of prior assumptions derived from experience through reflection, defined here as a deliberate process whereby experiential events (both physical and cognitive) are recalled, relived and "unpacked", and through a series of trials and errors connected with what one perceives as related concepts or phenomena. Restructuring (or reflective) strategies have one or more of the following characteristics: that they provide encouragement and opportunities for the learners to

1. remember and reflect upon their prior beliefs or new learning experiences;
2. communicate their thinking with others;
3. negotiate their ideas with their peers, their teacher, themselves,

and the phenomena;

4. experience some "discrepant events" intended to provide the discomfort which motivates conceptual change;

5. generate a variety of alternate hypotheses from which a fruitful alternative can be selected; and

6. reflect upon new learning experiences, and compare any new thinking against their prior assumptions.

The "P. O. E." sequence is one such restructuring strategy. Prediction, in addition to its value as an elicitation tool, is an expression of a preliminary hypothesis that provides an entry reference point upon which the learner can reflect following a deliberate experience. The Observation phase represents the interaction with a phenomena which may result in the verification or falsification of the hypothesis, functioning in the latter case as a discrepant event rather like a puzzle piece that does not fit. Explanation is the new meaning constructed out of the social negotiation of ideas.

The sequence may be illustrated and applied to an example. Let's go back to the student's notion that gravity is a magnetic field. He reasoned that metals are heavier as a consequence of this effect, forming the basis for his prediction. One significant test would be to compare the weights and magnetic properties of iron (magnetic and "heavy"), lead (non-magnetic and "heavier") and liquid oxygen (slightly magnetic, yet "light"). If the observations are acceptable to the student (and this may sometimes take some convincing) they may be seen as irreconcilable with the hypothesis. Through brainstorming of alternative hypotheses, debating and retesting, a more fruitful alternative may be sought. Other properties of "light" and "heavy" matter might be introduced which may include the shape or volume of the object, or the size, number and spacing of the molecules of which it is comprised. The teacher should be prepared to introduce relevant and preferably observable data as the need arises, perhaps giving evidence of the gravitational effects on different amounts of the same matter; planets of different masses; perhaps demonstrating that volume need not be a measure of the amount of matter by showing the compressibility of low density materials; comparing the weights of the same piece of modelling clay formed into different shapes; and so on. Frequent conceptual checks are needed at many points in the discussion to stop and take stock of the status of their thinking, or to compare and contrast ideas among students, and to provide spot summaries and review of purpose, rather like the charting of one's journey on a map. A "reflective summary" is the student's own recapitulation of the learning

event in terms of the modification of ideas and the significant factors involved in bringing it about.

The "journal method" described by Kuhn (1987) incorporates the learning events and the personal "sense-making" of the student in a written form in a journal-style notebook. The general format for the organization of the journal records includes the following components:

Prequestions: as an orientation to critical concepts, these are set by both teacher and students;

Preconceptions: students' responses to the prequestions (these will in part guide the subsequent instruction);

What Happened: learners' observations and descriptions of certain experimental phenomena;

Assessment: a reflection on the observations and explanations, particularly in terms of what they knew before;

Personal notes: personal views, new and unanswered questions, or any insights or extensions that they consider relevant;

Conclusions: a review of the objectives and activities of the topic briefly stating the main findings.

"Debriefing stems" serve the similar function of guiding meaningful interpretations taken from an experience, and to unpack the procedural, emotional, cognitive and conjectural components as a "jump start" to reflection. Some examples of debriefing stems are given below.

What I did...
How I felt about it...
What I learned...
An example (or analogy) of this would be...
I used to believe... because...
I was surprised that...
I would predict that...
I wonder if...
What I still don't understand is...

Whatever the restructuring plans it is obvious that they will not stand unsupported, but that there are certain characteristics of teacher behaviour upon which the success of such tactics largely depends. Two general classes of teacher behaviours will be underscored here: enabling and modelling.

Enabling behaviours involve:

1) identifying and logically sequencing significant concepts;

2) tracking students' ideas as they expand and evolve at both the

collective and individual levels;
3) the sorting out and clarifying of multiple views shared among students;
4) identifying and highlighting those views which appear to conflict;
5) making connections between student experiences and the common meanings they put to terms;
6) constructing connections among ideas articulated by students;
7) construction of appropriate images and relationships with relevant or analogous concepts; and
8) providing significant input concerning observable, verifiable data through either documentation or experience.

These "actions" pertain mostly to the creation of the critical moments when the learners "reformat" their thinking (if I may borrow the jargon from an analogous setting). Most are behaviours of skill; for example, the interpretive verbalization for decoding student language or the ability to trace the structure of discussions or lessons as they develop. But the actual execution of the actions themselves have the characteristics of an artform.

Effective teacher management enables the negotiation between the public and private deliberations. The discrete skills involved in this improvisational restructuring process are intangible, variable across contexts of content and clientele and are pivotal on the experiences of the teacher. They are, in fact, much easier to demonstrate than they are to articulate. Schon (1983) has described the nature of reflection in professional practice and states that the professional "knows more than he can say", unconsciously framing multiple microproblems upon which tentative hypotheses are repeatedly acted upon and tested in recursive experimental process that he terms "reflection-in-action". The upshot of this is that any practice as complex as this is difficult to reduce to "rules of thumb".

The second class of teacher behaviours for teaching for restructuring is modelling. It is asserted here that modelling--and by that I mean situations arising between individuals where the behaviours of one are considered worthwhile and desirable or merely accepted as standard practice by the other--is one of the most potent form of instruction, whether or not that instruction is intentional! I am humbly reminded of a slogan I read spray painted on the outside wall of a school gymnasium not long ago, the author no doubt eager to share the perspective of his culture with those of us in quite another: "Teachers, we know more than you teach us!" Below it I was tempted to add: "Students,

we teach you more than you know!" (but then that is not the kind of action I would want to model for them!). Dewey (1933) expresses a similar thought in rather more sophisticated terms:

> "Perhaps the greatest of all pedagogical fallacies is the notion that a person learns only the particular thing he is studying at the time. Collateral learning in the way of formation of enduring attitudes, of likes and dislikes, may be and often is much more important than the spelling lesson or lesson in geography or history that is learned."

A science teacher may give instruction on the characteristics of "good scientists" and their formal method of inquiry in an upfront, didactic manner, but students are quick to notice any inconsistencies if the teacher is observed to demonstrate contradictory practice. In the same vein, teachers who demonstrate a notion of science as a fixed body of knowledge to be found in "the book" and who, furthermore, express an intolerance for any ideas from students which conflict with these statements of fact, are likely to promote similar attitudes in their students.

TRAINING THE CONSTRUCTIVIST TEACHER

I. Practicum Coaching

In a case study by MacKinnon (1988), two student teachers were observed in the practicum setting as they were respectively coached by school supervisors who were [SI]^2 teachers. Videotapes and transcripts were made of several lessons taught by both students and supervising teachers, and of interviews and debriefing sessions between them. Two implicit goals of the supervising teachers in this practicum, quite evident in retrospect, were to: 1) coach and encourage the student teacher to put constructivist teaching strategies into practice, and 2) to use constructivist strategies in the coaching of student teachers.

MacKinnon identified two coaching models which are consistent with Schon (1987). The "follow me" model had the supervising teacher conducting a science lesson and, with the help of transcripts and videotape, subsequently underscoring some particular teaching strategies for the benefit of the student. In the course of the practicum many of the teacher's strategies and elements of his style were evident in the student's practice.

The other model has been coined the "Hall of Mirrors". This is a reflective model where

> "The two models--one of science teaching, the other of science teaching practicum--are then superimposed, resulting in a "Hall of Mirrors" model, designed to broadly define areas where the practice of supervision mirrors the practice of science teaching that the student teacher is attempting to acquire." (MacKinnon, 1988)

MacKinnon illustrates the interactions among the students (S), the teacher (T) and the natural phenomena (NP) in a constructivist science classroom as shown in figure 2. Note the mutually interactive connections between each of the components representing reflection upon experience and negotiation of interpretations.

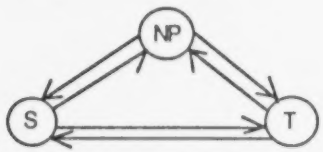

FIGURE 2: "Pedagogy of a Natural Phenomenon"

Now if one considers this conceptualization as a phenomenon in itself (TP) upon which observations, reflections and negotiation of interpretations can be made by and between the supervising teacher (SpT) and the student teacher (StT) for the duplicate purpose of "sense-making", the diagram is modified slightly. (Figure 3)

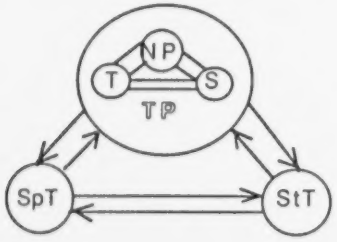

FIGURE 3: "Pedagogy of a Teaching Phenomenon"

In the following excerpt of transcripted dialogue, the supervising teacher ("Gary" is a pseudonym for the author) and the student teacher ("Kevin") are viewing a videotape of Gary's lesson on the thermal expansion of solids. Gary is encouraging Kevin to identify and reflect upon some of the characteristics of an interpretive discussion in the "predict-observe-explain" sequence that he is modelling.

G: Over the last few minutes of this lesson, you can see that we're in a discussion mode here, and

I'm just curious to know if you have any observations of the kind of strategies that I'm using in the discussion.

K: Well, I've noticed a number of things. First of all, the students are making a number of predictions and there seems to be no lack of involvement. Or, you don't seem to really be prying predictions out of these kids. There's a fair amount of openness that you've developed in the classroom.

G: That they'll respond . . .

K: Yeah.

G: . . . and volunteer without being . . .

K: That's very impressive. I mean, the kids are ready and willing to give some predictions. And, I mean, and that takes a certain amount of risk.

G: That's right.

K: Because they could be way off base with some of these predictions.

G: Actually, that's really important. Can you think of any ways that you could develop that. . . that sense of trust really?

K: Well for one, with their predictions, all of your answers are very neutral. You don't in any way give any teacher signs as to they're on the right track, or. . . you seem to accept them all with the same, "I see." And, perhaps, ask for further clarification or just elaborations. And. . . as a student I would find that very easy to respond to. . . maybe wanting a bit more out of you, but you don't seem to be giving it to them right yet.

G: Okay.

K: And I noticed as well when you were responding to one of the students, you related it back to another student's remarks. Therefore, the student. . . the first student feels that his remark had some value. And the second student, you know, you link up their. . . even though she was actually contradicting the initial prediction, it was. . . there was a link made, so they felt that both of them had weight. And they would be able to wait and see with one, perhaps, was right.

G: Okay, good. All right, so. . . a sense of trust. . .

K; Definitely, yeah.

G: And. . . uh . . .

K: They have. . . well, and that trust allows them to take risks.

G: Okay, all right. And what I'm asking these kids to do is really to lay their souls bare in the sense of what do they really believe to be true.

K: Exactly.

G: . . . not being tested by any observations at his point

K: Evaluations.

G: They're just saying what they think would happen.

K: Exactly.

G: And, yeah, there's a lot of risk in that. And it does take a while. Is there anything else that you notice in the discussion? Is. . .

K: Well, in their prediction, they. . . one student would make a prediction and I notice you would either paraphrase or ask for clarification. And I guess there's a number of reasons for that?

G: Can you think of any?

K: Uhm. . . certainly the clarification is for you to be able to relate to the student if you're not exactly sure what he's saying. . .

G: Okay.

K: Also it allows him to really redefine what he's saying. He can work it through in his mind as he speaks it out, and that's probably a very important part. In terms of paraphrasing, that allows the whole class to become part of that answer, because often times kids throughout the class don't necessarily hear a response.

G: Actually I did quite a bit in this particular segment just because. . . probably more than I would ordinarily do in a classroom situation just for the benefit of the microphones that were in the classroom to pick it up.

K: Right.

G: And some students have very soft voices, and just to ensure that it was actually picked up. But you're right. And you've picked up a number of things. One is to check the meaning of the student, to make sure that what I understand him or her to mean is in fact what they intended to say.

K: Yeah.

G: It sometimes gets confused when they are using their own language, and they're not using our kind of scientific language. And they will often use words, well as we learned today, heat and temperature, kind of interchangeably.

K: Exactly.

G: And they will say heat when they mean temperature. And unless you kind of check for clarification as to what they really did mean, we can sometimes be misled.

K: And so paraphrasing would help you do that.

G: And paraphrasing would help that. A useful exercise, too, sometimes. . . I think I might have done it here once or twice. . . is to get other students to paraphrase what one student has said.

K: Right. That not only says, "Hey, you'd better be awake and listening," but it also says "Do you understand what they were saying. . . can you derive some sort of meaning on your own?"

MacKinnon notes that this interchange is very much like the interpretive discussion "Gary" holds with his students, and points out the super-imposed image of "Gary elicit(ing) Kevin's ideas about a technique designed to elicit students' ideas" and of "Gary paraphras(ing) Kevin's ideas about paraphrasing students' ideas."

If strategies employed by constructivist teachers are deemed to be worthwhile and effective in the coaching of preservice teachers it is because there are parallels between students of science and students of science teaching. To begin with, all student teachers have had many years of prior experience as students, and as such, have had a great deal of opportunity to observe teaching "acts", a variety of teacher "models" and to make sense-making generalizations about the role of teachers and the nature of teaching and learning. The same can be said about the formation of preconceptions about particular subject areas which includes science. Since all sets of experiences are unique to the individual, the construction of knowledge about "science teaching" is also personal and unique; and since those experiences have been incomplete and unordered, the consequent beliefs may well be inconsistent with contemporary views about learning theory and instructional practice. It is similarly likely that such prior ideas may influence the meaning constructed from the pedagogy of teacher training or cause one to prematurely judge the "worth" of particular sorts of teaching practice.

There is evidence to suggest that particular attitudes and beliefs about the nature of science, the roles of the teacher and of the student, and the teaching/learning process are often tightly held. Examples of beliefs commonly held by student teachers include: "the role of teacher as explainer"; "science has the right answers"; or that "a right answer indicates that the student understands". As is the case with other learners a deep, personal and committed understanding only follows a conceptual change; that is to say, not only must a concept be seen as "intelligible" (understandable) and "plausible" (believable), it must also be "fruitful" (the most attractive of the alternatives and therefore preferable) if it is to be adopted. Transmissive didactic strategies are

usually limited in their effect to the attainment of the first two, whereas the intention of constructivist strategies is to promote the personal ownership of new knowledge.

The principles underlying the restructuring strategies developed in the context of classroom instruction were similarly implemented in preservice training at the levels of Methods instruction at the university and of coaching by the supervising teacher. A partial list of constructivist coaching strategies consistent with those principles is provided here.

1. Provide a safe, supportive and forgiving environment where there is, as much as possible, a freedom to make mistakes (realizing that the forgiveness of the students can never be promised!)

2. Provide objective, non-evaluative feedback for a lesson from which the student is encouraged to make his/her own interpretations.

3 .Demonstrate particular strategies which the student can mimic as a kind of "instructional kick start". New practice can be tried on like new shoes, and explored from within one's comfort zone where the outcome is more or less predictable and teacher actions are made more specific.

4. Make videotapes of the lessons of both the student and supervising teacher and use them as a focal point for reflective interviews.

5. Switch roles and have the student teacher criticize the lesson of the supervising teacher. Evaluating teacher practice requires that one must make the tacit rules of teaching explicit and as such it is a valuable reflective exercise.

6. Raise questions about the possible meanings of interesting student utterances. This not only *models a disposition* to "give students reason", but provides an occasion for the student teacher where the exploring of childrens' alternate conceptions can be practiced with the benefit of the supervisor's repertoire of experience with childrens' thinking.

7. Model the desirable attitudes and behaviours of teachers such as: openmindedness, suspension of judgement, inquisitiveness, respect for students as individuals, objectivity, honest self-appraisal, fairness, encouragement, tolerance, and the disposition to think critically. It is a weighty responsibility indeed--not to mention a considerable strain--to be expected to behave as an immaculate model! Yet, the influence of the role model can not be underestimated, particularly when the model is seen as a "coach", "mentor" or as an example or perhaps even an embodiment of the profession as a whole. Or simply by default, from the evidence of long and successful experience the set of behaviours of the model are seen to be effective traits for survival--however else one might view them.

8. Encourage the student teacher to view instructional practice from the learners' perspective and by so doing, develop a sense of the possible implications or impact. This may involve developing a theme from a naive but concrete and familiar starting point, then identifying and logically sequencing the necessary preconcepts in the construction of main ideas. It may mean coming to terms with what students would consider personally relevant or familiar to begin with, or perhaps anticipating areas of comprehension difficulties which may be manifestations of alternate conceptions or incomplete experiences. Obviously a repertoire of experiences with these learners would be an asset in the anticipation and remediation of their understandings. Lacking these, the novice will need to rely on the supervising teacher for support in developing appropriate models, analogies, examples and language.

9. To serve in the function as "seeing eye dog" in guiding inquiry into classroom phenomena by calling attention to those things not apparent to the novice. Experience leads one to identify and ascribe appropriate significance to the nuances of student behaviours that give clues to the classroom dynamic or student thinking. Inexperience in this setting is not quite the same as having a sensory handicap, however. The novice suffers more from sensory overload than deprivation and has difficulty discriminating between the "foreground" and the "background", occasionally resulting in inappropriate decisions of action. A student teacher once likened practice teaching to learning a new sport. At the beginning it seems like all the action is in fast-forward as events unravel faster than one can properly react to them. With continued practice, however, the action seems to slow down, giving more to anticipate, deliberate and react.

10. Recognize the need for the assimilation of new language. As a parallel to the science student learning to comprehend and exercise the special language of science, the student teacher will need to develop a sense of the common language of students and to acquire a shared meaning of the language of teaching with the supervisors. It should be understood that:

a) without shared language communication is confounded;
b) clear communication is a prerequisite for comprehensible instruction and effective coaching;
c) "fluency" will be enhanced with some deliberate direction and practice; and,
d) fluency in any new language requires a period of time to develop.

11. Conduct reflective interviews where the student is guided to "name

and frame the problems" (Schon, 1983), to generate hypotheses about the factors leading to the problem and alternative strategies which might be tried, and to evaluate these and decide on a tentative course of action. The problem, chosen action, observations of the results and interpretations thereof are rather like the components of a "P. O. E." sequence and is guided practice for "reflection-on-action" described by Schon (1983). Reflective interviews have an identical function to the interpretive discussions mentioned earlier--an enabling opportunity for the construction of the learners' personal meaning from experience.

The ability to reflect on one's own performance is central to the notion of professionalism. Defensiveness about one's practice in response to evidence of contradiction is symptomatic of an unwillingness to reflect and can be a block to professional growth. From a constructivist perspective, a defensive reaction is an indication of a deeply held prior belief about a particular concept or attitude. As with other students, restructuring is promoted with the exposure to discrepant realities and the selection of fruitful alternatives. But some beliefs are more deeply held than others. Surface level beliefs may be regarded as "ideas" and are relatively changeable under the light of contradictory evidence, whereas deeply rooted beliefs, like "values", are woven into one's personal fabric and are not likely to change solely on the strength of logic. It is recognized, therefore, that restructuring for conceptual change is not always possible, and it may in fact raise a broad ethical question in some instances about the propriety of trying to impose change of beliefs which may be anchored at the values level.

2. <u>"Methods" Instruction</u>

With reference to Driver's constructivist teaching sequence, pre-practicum instruction is rather like an elaborate "orientation/ elicitation" phase to the development of the knowledge, skills and attitudes involved in teacher training, while the practicum itself crudely corresponds to "restructuring" and "application".

There are, of course, certain aspects of preservice development which are traditionally held to be unique to the theoretical phase of teacher training. Exposure to diverse literature brings an awareness to the student of the results of research on a wide array of instructional factors as they relate to achievement, theories of adolescent psychology as they relate to the characteristics of student behaviour and management, and discourse on the relationship between classrooms and the broader cultural, philosophical, and curricular domains. Teachers are

practical people and only casual empiricists, and are not as likely to relate aspects of their practice to the same level of theory. Similarly, the university setting offers limited opportunity for the student to act out the aspects of practice. Hence the endless seesaw debate and ultimate compromise between theory and practice which are stereotypically assigned to each setting.

My new position as methods instructor--arising partly as an offshoot of the [SI]^2 Project--was an attempt to mediate the extremes. As a classroom teacher of a dozen years and a sponsor of as many student teachers, it was felt that I could bring a credible degree of practical experience to the role, while my studies and experience with the [SI]^2 Project gave me a reasonable theoretical perspective on teaching practice. Coming as I was from a constructivist base I made a committed attempt to implement an instructional program consistent with its tenets. A number of strategies I implemented are itemized below.

1. A questionnaire was employed as a "pre-instructional dipstick" to elicit the students' preconceptions about their notions of science and of teaching. It included the following questions:

-"What does the word **science** mean to you?"
-"How do you think scientific knowledge has been produced?"
-"Why do you want to be a science teacher?"
-"How would you consider the students' own theories in your teaching, if at all?"
-"Give your own metaphor for the teaching/learning process."
-"If you can, briefly describe your own "theory" about how learning occurs."

2. The "Theory Box" is a contraption containing a rather complex mechanism although from the outside one sees only a funnel leading into the top and a rubber tubing protruding from the bottom. (Figure 4.) Students are asked to predict the result when 100 mL of water is poured into the funnel, then their predictions are tested. About 97 mL of blue liquid is collected under the rubber tubing, and they are invited to develop an explanation about the contents of the box and share these explanations through discussion. When then asked how to test their hypotheses, most would suggest a repeat procedure with results varying according to the model proposed by each student. The result on the second trial is about 99 mL of yellow liquid. Typically, students respond with surprise followed by confusion as they demonstrate their dissatisfaction with their models. Revised explanations tend more to be modifications rather

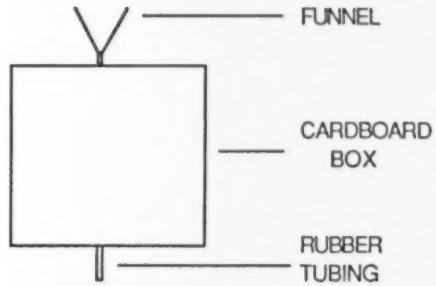

FIGURE 4: "The Theory Box"

than substantive reconceptualizations of the preliminary models. Repetitions result in about 100 mL of clear liquid, and finally about 40 mL of yellow liquid, at which time there is usually considerable rethinking on the part of students amid a barrage of extraordinary comments!

The theory box represents an unfamiliar phenomenon around which students may engineer sense-making constructions from the conceptual connections of their own familiar experiences. In this sense their predicament parallels that of novice science students exposed to unfamiliar themes or situations, or indeed to that of scientists exploring the uncharted frontiers of their fields of inquiry. It is an opportunity to model for them some constructivist teaching strategies such as the components of the P. O. E. sequence or the characteristics of an interpretive discussion and negotiation of ideas. At the personal level the unexpected outcomes observed, like the discrepant events mentioned earlier, create the discomfort which necessitates conceptual change. At the social level this experience models the punctuated equilibrium of the evolution of scientific knowledge which Kuhn (1962) termed the "scientific revolutions" of the scientific community.

The nature of scientific knowledge is called into question after it is made clear that the contents of the box will not be divulged. (This is not always well received, by the way!) But if the behaviour of the mechanism represents an observable and to some degree testable phenomenon, then what would be the analogous counterpart of "The Right Answer"? What is the structure of an atom? Why do cells divide? What was the state of space and time at the beginning of the universe? The concept that there is no objective reality and that the mechanism of the theory box is whatever one could devise which would satisfactorily account for the observed

results (suggesting both simultaneous and mutable models) tends to raise conceptual dissonance. Contradiction is a necessary but not sufficient condition for change, although realistically, beliefs about the nature of science held by individuals with a B. Sc. degree can be rather deeply rooted and are unlikely to change easily or with a single experience.

3. Students were exposed to a selection of the literature on constructivism, notably Osborne and Freyberg (1986), Driver and Oldham (1986), Driver and Erickson (1983), and some of the practical writings from the [SI]^2 Group. Opportunity was given in class to discuss, interact with and reflect on the readings, and to make connections wherever possible between illuminated concepts and strategies and other pedagogical phenomena under review.

4. As stated earlier, the modelling of desirable strategies, procedures and attitudes is considered to be of critical importance to effective instruction. This was displayed in three ways: instructor behaviour, "pedagogical exemplars" and guest presentations.

The instructor may overtly or covertly model inquiry methods, science demonstration activities, discussion techniques, questioning, conceptual development, communication skills, problem solving, techniques for personalizing new information, and attitudes such as curiosity, suspension of judgement, fairmindedness, objectivity, and the disposition to elicit and respect student ideas. Ever mindful of the credibility loss inherent in inconsistency, it must be said that this is a somewhat onerous task!

The "pedagogical exemplars" consisted of videotapes of teaching episodes in the classrooms of the [SI]^2 teachers. These vignettes illustrated concept mapping, cartooning, P. O. E. sequences, interpretive discussions, and practicum dialogues between student teachers and their supervising teachers. Subsequent comments made by some of the students both then and thereafter seemed to indicate that these were significant events in that formative phase of their training. For the majority those views of the classroom were the first that they had seen since they were students themselves, and the power that modelling had for them at that particular stage was apparent. Further, by virtue of the nature of the medium the characteristics of the modelling can be controlled and defined to some degree, contributing to their instructional value.

Thirdly, [SI]^2 teachers were invited to present their own perspectives and strategies and to bring examples of their students' work as illustrations of the products of these kinds of instruction. As well as a representation of exemplary practice, this served to further establish

relevance and credibility in the context of the classroom.

5. Reflection--looking back and looking within--is the connection between experience and meaning. Effective teaching ought to provide both the opportunities to reflect and the strategies to enable reflection, whereas effective modelling will develop the disposition. With this intention, three manoeuvres will be discussed: definition and emphasis, the practicum journal, and peer demonstrations.

Establishing the characteristics of reflective behaviour and establishing the importance of reflection on learning (by pupils, teachers, or in fact anyone seeking professional growth) is fundamental. It occurs to me now that this, like any other concept, will not be internalized without experience and reflection. To reflect on practice ("reflection-on-action" as termed by Schon) is somewhat difficult to do in a pre-practicum setting, and it is something over which the practicum supervisors have considerably more influence. Giving isolated advice about "reflection" outside the context of practice is about as futile as hanging a sign over one's desk that says "Think!". One can only hope that it resurfaces at a later and more appropriate time as a posthypnotic suggestion!

The "Practicum Journal" was intended as a prescribed opportunity to practice reflection-in-practice while motivating students to heighten their awareness of the school ethos and extract personal meaning from it. The Teacher Training programme at U. B. C. arranges for a two week minor practicum midway through the fall term, while the major extended practicum begins in January for thirteen weeks. As a requirement of the General Science Methods course, students were asked to keep a journal which documented their preliminary experiences in school society. The suggested format was an analogue to the P. O. E. Prior to this first experience they were asked to state their preconceptions, anticipations, assumptions and apprehensions about students, teachers, teaching and the school culture; during the two weeks they were to document their ongoing experiences, interactions, significant events or conversations, and immediate impressions; and at the conclusion, to summarize and reflect on the new meanings, generalizations, surprises (contradictions to the anticipations), retroactive impressions, and possible resolutions for further practice.

Student teachers are in a unique circumstance at this time. They are at once students and teachers, while in another sense are neither of these. Truly "strangers in a strange land", they are engulfed in a peculiarly foreign and familiar world and in quite a vulnerable condition. By adopting

a reflective stance somewhat psychologically removed from the events they perpend, they may be better disposed to find security and meaning. These themes of vulnerability, revelation and candid perspective were evident from many of the journal entries.

"Peer demonstrations" were microteaching events where students took turns showing the class particular science phenomena. It was an opportunity for each individual to practise skills of equipment manipulation and safety; communication in terms of verbal, tactile and visual explanations; and conceptual development, since they were also required to place the demonstration into some curricular context and use it to develop a particular concept and to indicate how and with what else it might be integrated. It also provided an opportunity to identify and reflect upon a multitude of teaching characteristics in the course of the summary critiques. The instructor's role was to insure that the environment is constructive and "safe" (i.e. low risk--there was no evaluation on the "lesson", only upon the physical organization for the demonstration itself), that salient points of teaching are identified (recognizing that the novice is often poorly equipped to "unpack" a complex episode), and that students are challenged to create variations and new contextual applications from the demonstrations they review.

As a further aid to reflection, students had the option of having their peer demonstration videotaped so that they might view their own "performance". If they wished, I would view it with them so that jointly we could unravel and reconstruct the episode in detail.

A "PARALLAX VIEW"

An advantage of having acted out the roles of teacher, practicum coach, methods instructor and faculty advisor (my memory as a student is only faint, which is unfortunate since it is probably the most valuable perspective of all!) is that it brings much to bear on the practical sense-making of teaching phenomena. To me it is analogous to viewing a scene simultaneously from multiple vantage points, affording one a three-dimensional view. This type of depth perception is especially evident when the classroom is seen from the candid perspective of a faculty advisor on practicum visitations.

But to extend the metaphor, although the external view offers much clarity, the distance makes meaningful and practical involvement difficult. To the student teacher the faculty advisor is seen not as a coach, but as an external evaluator for whom special lessons are prepared that he might be favourably impressed on his weekly visits. Criticisms or

suggestions are occasionally met with defensive reactions which may indicate a perception of irrelevance in the context of the student's situation. One interpretation of this perception is that the faculty advisor is not seen as a representative of the system which imposes the constraints under which the student teacher must operate. To a large degree, of course, this is true. Consequently, one's value or effectiveness as a coach while in this role is severely limited.

Another limitation to the faculty advisor's ability to coach effectively is the lack of opportunity to model desired teaching behaviours. It is difficult for the student to implement verbal descriptions of complex practice unless: 1) there is also an observable model which may be mimicked; and/or 2) there is frequent and sustained feedback in guided practice. Let me illustrate with the following "Hall of Mirrors" example.

I recently observed the lesson of a student teacher whom I will call "Rick" as he developed the concept of "absolute zero" with his grade eight class. He began by asking if anyone had ever heard the term absolute zero or if anyone knew what it meant. Nobody did, so he went on to explain how it is the lowest possible temperature since that is the point at which particles essentially have no energy. (I suspect that he was acting out of his own preconception about the role of a teacher as "explainer"). Later, I asked him to think of other ways of developing the concept, or specifically, relating the concept to the term. We talked about encouraging students to make sense of the notion of a lowest possible temperature (perhaps by reviewing the relationship between particle energy and temperature, describing the relative motions of particles at boiling point, room temperature, freezing point, winter in Winnipeg and down until the particles "stopped") and *then* putting a name to it. Once Rick had made sense of this strategy and made some intuitive links between this and his own theories of effective learning, I defined it for him as what Hawkins had termed "conceptualization before formalization" and in so doing, I formalized it. However, my only available avenue for establishing that conceptualization was through dialogue rather than by modelling and guided practice. Consequently, the new ideas are expressed and recalled simply as declarative knowledge rather than as deeper, tacit knowledge.

I would assert that the rules of teaching must be practised, experienced and internalized before they are rendered valid and memorable by the novice. Knowing by rote is much less effective. Put another way, "knowing what to do" is not equivalent to "doing what you know". The difference comes from exercising situation-specific theories of action

where there is simultaneous transference between theory and practice; where practice is borne out of the direct application of theory, and tacit theory is constructed directly out of practice. An effective coach can identify those principles of teaching worthy of remediation and seize the opportunity to manoeuvre the student into a teaching experience so that that principle may become apparent, credible and personal. Pure theory delivered in the context of coursework is "knowing formally before knowing intuitively", as Hawkins puts it, and largely ineffective in impacting conceptualization in meaningful and purposeful ways.

What this implies is the extremely powerful influence of the supervising teacher on teacher training. This, of course, has both an up and a down side depending upon the characteristics that the supervising teacher has a propensity to model, in the same way that teachers are modelling attitudes and processes about the science they teach their pupils. Much of the current pedagogical research on effective practice, discourse on personal and social values and ethics, and the consideration of broad ideals which are presented in the university setting, is forgotten amid the "realities" of survivalism and the atmosphere of cynicism that prevails in many schools.

Perhaps the intention of pre-practicum instruction, apart from the obvious and traditional one of theoretical backfilling, should be to instill in the student a kind of "pedagogical conscience". In the impressionable, formative years of childhood, behaviours are moulded through repetitive, corrective reinforcement in a variety of situational contexts. For most, the rationale for a socially acceptable set of behaviours is eventually adopted, giving some magnitude to the "inner voice" that speaks to one of pride, honour, guilt, regret and encouragement for corrective reappraisal. Such is the "Conscience". When reared in an environment where a set of values contrary to those of the usual social norm are modelled and reinforced, an individual is probably more likely to develop personal values which reflect such an alternative, yet those values are intact and would certainly direct future behaviours. But I would suspect that a neutral environment would be manifest in an impressionable character with a tendency to easily conform to the pervasive attitudes. This rather simplistic rendering serves to illustrate the point that the values inherent in teaching practice are also set through modelling and reinforcement during the impressionable, formative initiation period of teacher training. These values are held only so long as they are believed, and they are believed only so long as they can be shown to be intelligible, plausible and fruitful (i. e. proven useful through personal utility) as is

the case with the conceptual constructions discussed at the beginning of this paper. Once the values of either specific strategies (such as giving students "reason") or particular attitudes or perspective towards teaching and learning (such as viewing student ideas as worthy of consideration) is understood and adopted at a personal level, the "pedagogical conscience" henceforth sits upon one's shoulder whispering self-correctives into the practitioner's ear when practice strays too far from the inbred ideals. This would be a valuable outcome of professional development.

Finally, it was noted earlier that a necessary precondition to conceptual change is the provision of a safe, low risk environment where one is free to experiment with ideas and explore alternate hypotheses. In this regard, however, the practicum tends to impose some constraints arising from the strong evaluative component of the experience. Whether real or imagined, the practicum is characteristically viewed as more of a "proving ground" than a "training ground". This *preconception* is held by student teachers, the schools and perspective employers alike and it is the foundation for an *alternate conception* in terms of the manner in which an unsuccessful teaching tactic is interpreted. The key to reflective practice and professional growth is the ability to view mistakes as "a source of discovery rather than an occasion for self defense" and to drop the "facade of infallibility" (Schon, 1983). What needs to be addressed is the contribution that the teacher training institutions and the schools make towards perpetuating this inhibiting attitude. I rather like the quotes of two individuals who evidently viewed mistakes as the "error" phase of the constructive "trial and error" recursive: "Experience is the name we give to our mistakes" (Oscar Wilde) and, "A life spent making mistakes is not only more honourable but more useful than a life spent doing nothing". (George Bernard Shaw) (Incidently, the latter quote was passed on to me by one of my grade nine science students in a response to my frequent appeals of, "It's O. K. to be "wrong" at this stage--I'm just interested to know what you think.")

SUMMARY

Three parallels have been drawn in the context of constructivist theory: promoting conceptual change as a basis for deep and personal understanding of science by school students; teacher training for the acquisition of the skills and dispositions to implement constructivist teaching; and the application of constructivist methodologies in the professional development of pre-service teachers.

The fundamentals of this perspective are germane to each. Learners bring their personal preconceptions with them to a course of instruction which influences their sense-making and their inclination to believe new ideas. This establishes the notion of learning as conceptual change, requiring effective restructuring methodologies which include the importance of modelling, exposure to discrepant events, guided practice in a low-risk environment, and ample opportunities in which to reflect on experiences and to negotiate the personal and social meanings of natural or pedagogical phenomena.

. The blurrier the distinction between theory and practice--stereotypically assigned to "researchers" and "practitioners" respectively--the greater is the relevance one has to the other. Hence, collaborative research involving school teachers and university personnel has great potential for mutual benefit as may be seen from the work of the [SI]^2 Project. An enhancement of and awareness about the restructuring components of teaching has considerable instructional value for both realms, but in particular, each group with their different yet compatible expertise have much to contribute in the shared problem of constructing new understandings about teacher practice and revelant professional development.

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